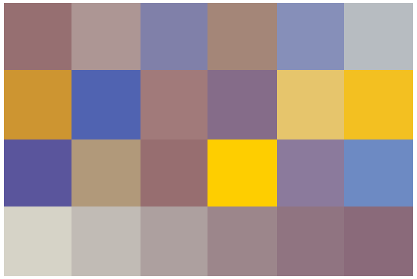




The Color Of Water

Using Underwater Photography to Estimate Water Quality

John Breneman IV, Henryk Blasinski, Joyce Farrell

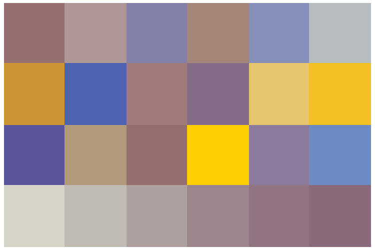
CASIS Workshop, LLNL

5/21/2014

Underwater color is a challenge

Surface color

Manual color



Standard color

Model-based color

This talk

1. Motivation

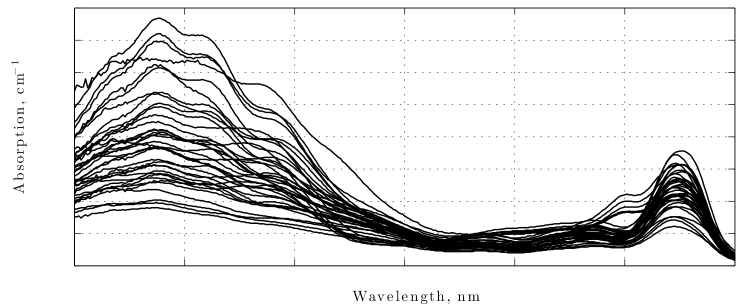
2. Extending the image formation model
   a. Spectral basis functions
   b. Medium scatter factors

3. Model evaluation
   a. Prediction of real world dive data
   b. Water content charts

4. Effect on color correction techniques
   a. 3x3 vs 3x4 color corrections

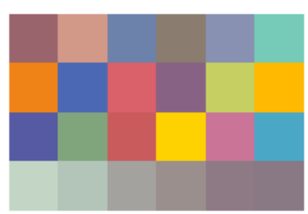
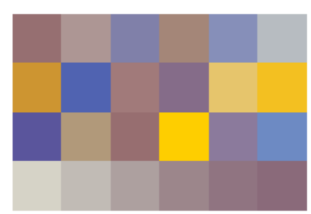
Why a physical model for underwater lighting?

1. Better understanding of oceanic composition
    - A. What's the "viz" at a popular dive site? Murky or Clear?
    - B. Is there a plankton bloom?

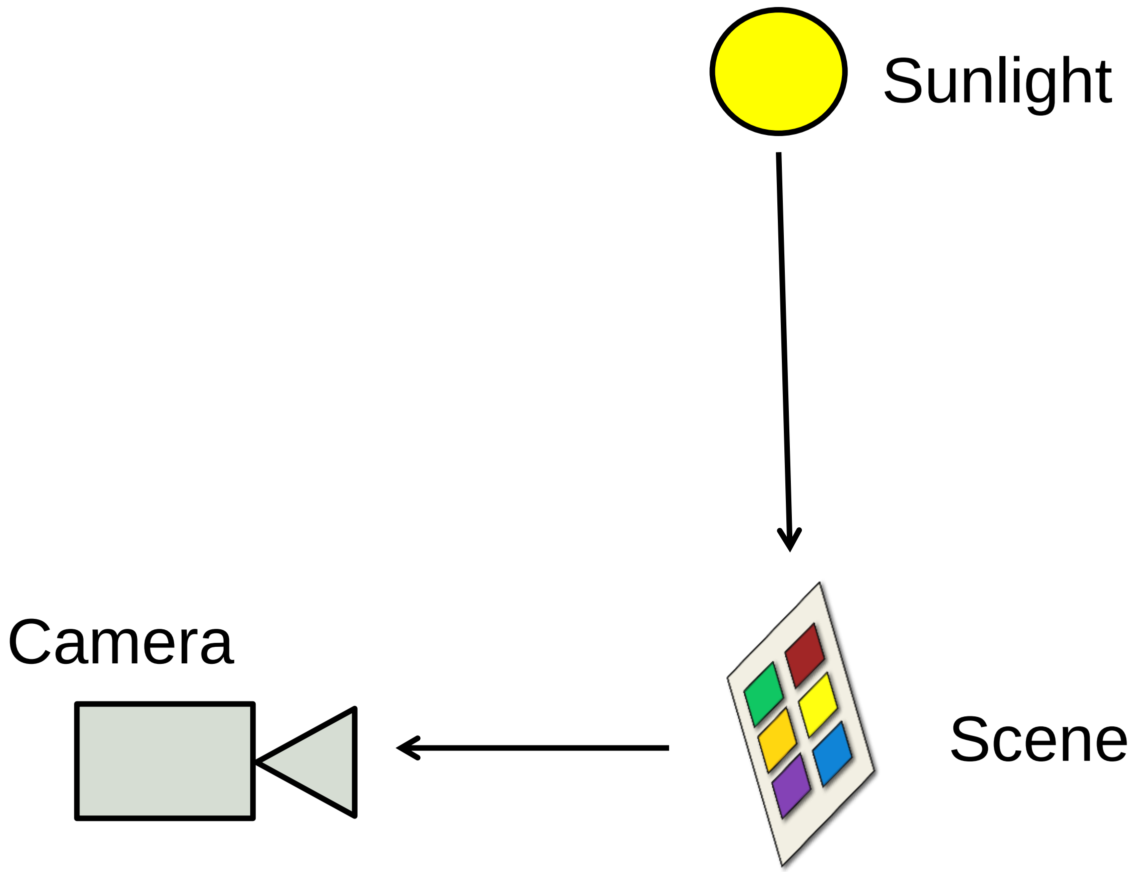


Roesler et al, 1989

2. Insights for correcting underwater color images
    - A. Why are underwater dive filters so popular?
    - B. What form should our color correction take?
    - C. How can we identify the best color transform for a picture?

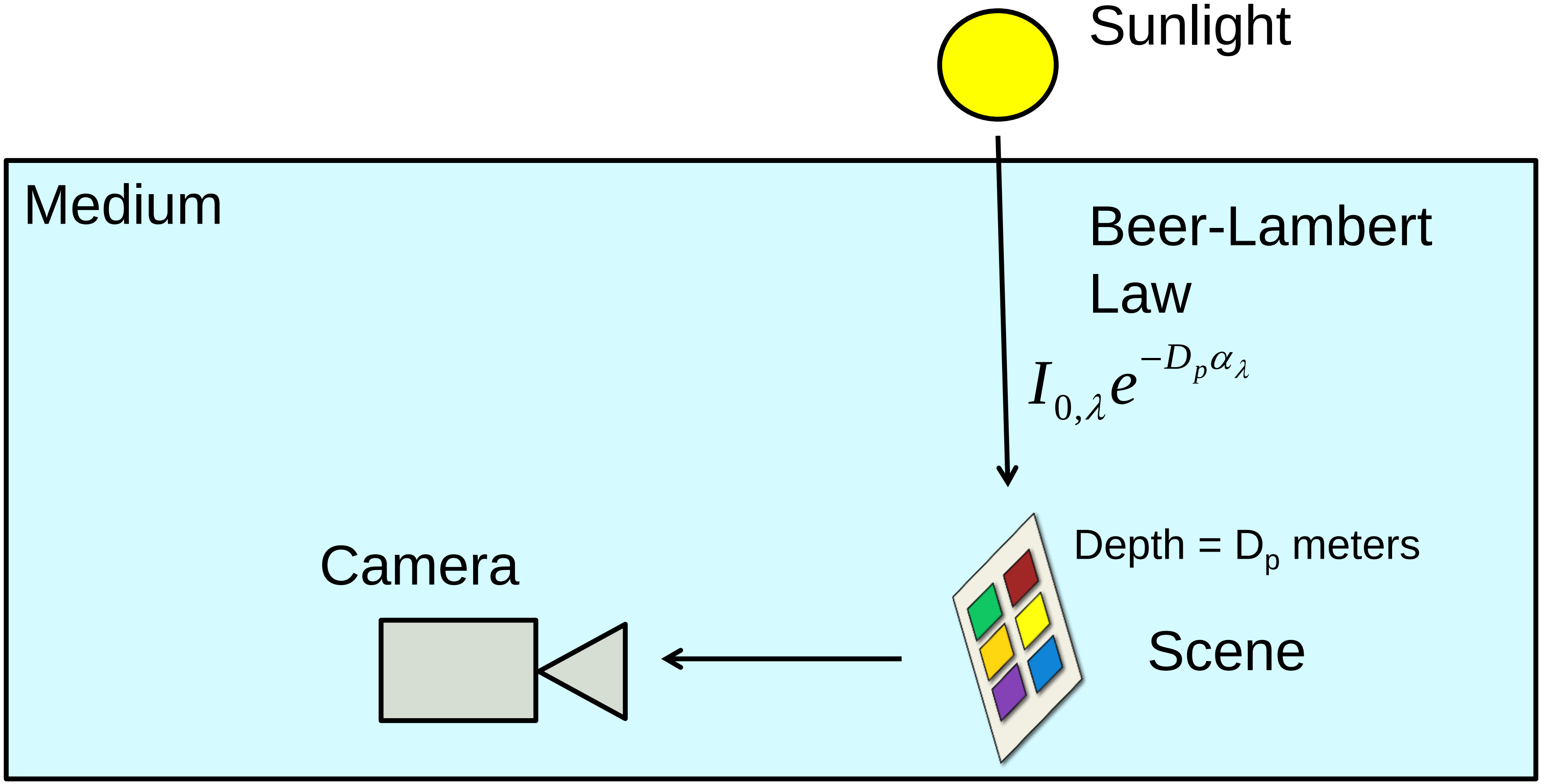




Standard Linear Image Formation Model



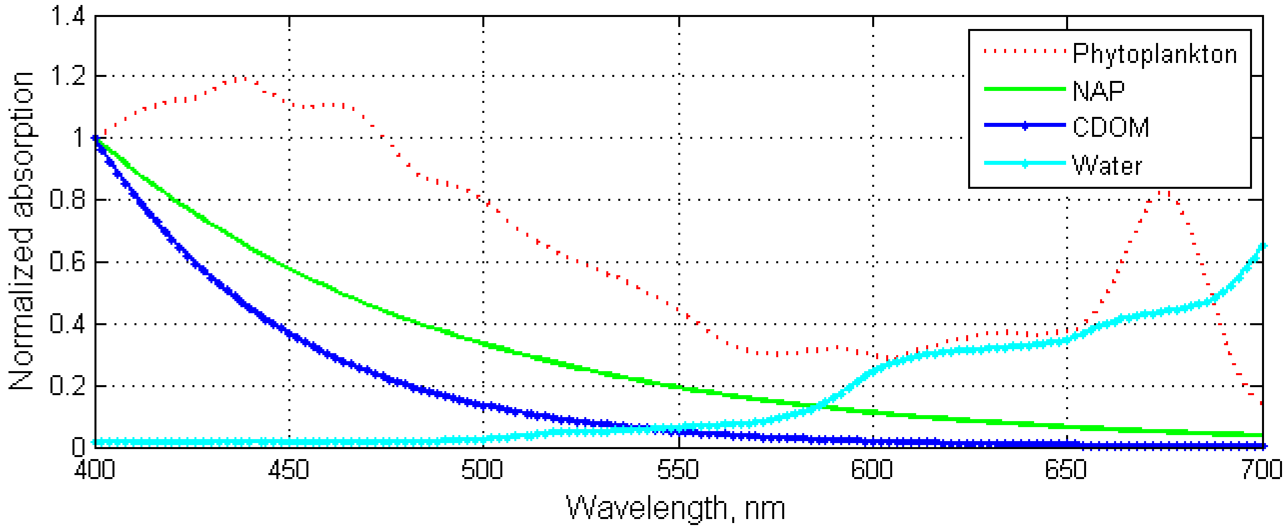
$$m_j = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_\lambda$$

Lossy Medium



$$m_j = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-D_p \alpha_\lambda}$$

Lossy Medium With Absorption Basis

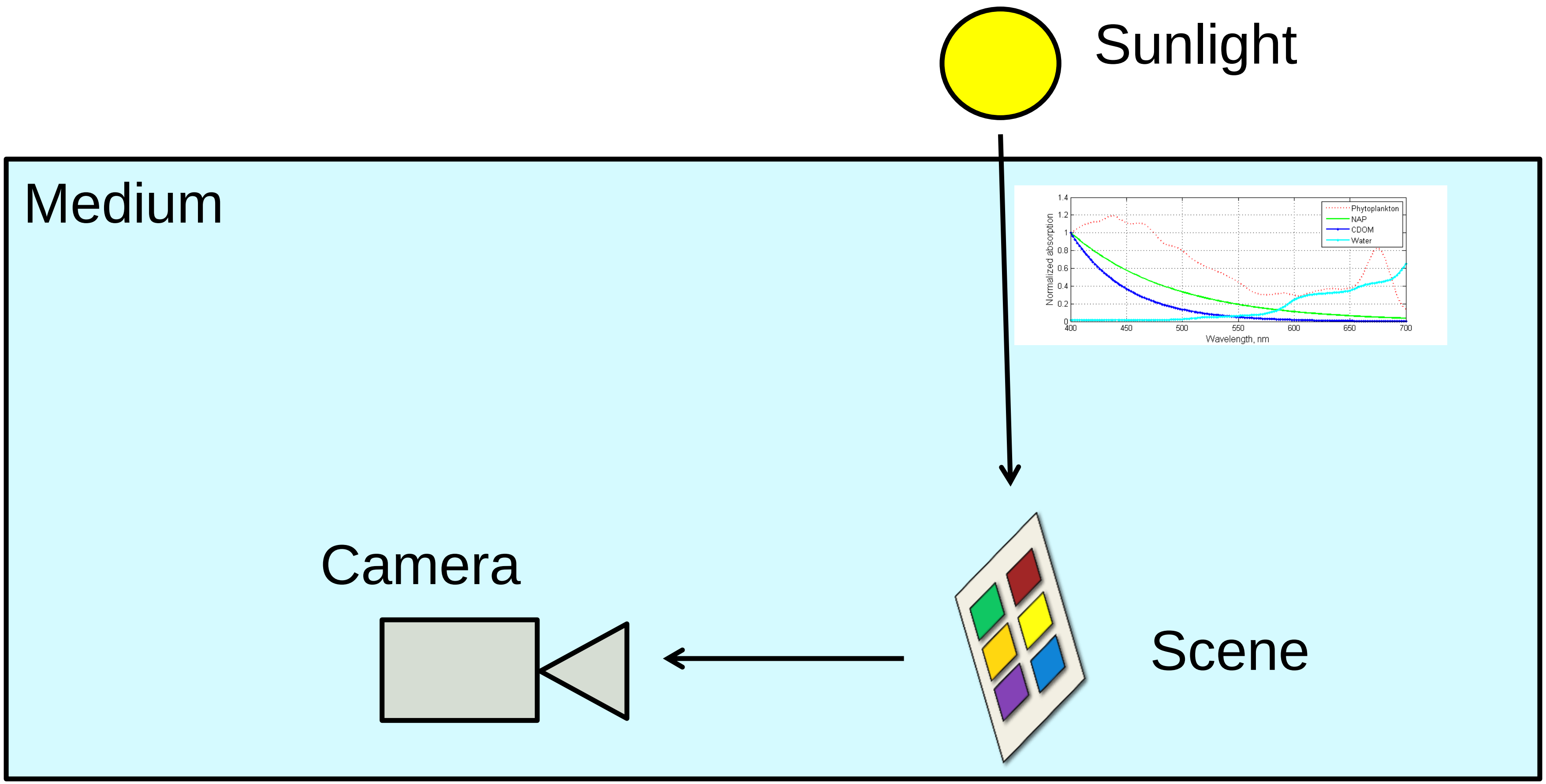


$$\alpha_\lambda = \alpha_{w,\lambda} + \alpha_{\Phi,\lambda} + \alpha_{CDOM,\lambda} + \alpha_{NAP,\lambda}$$

$$= \underbrace{\alpha_{w,\lambda} + c_\Phi \beta_{\Phi,\lambda} + c_{CDOM} \beta_{CDOM,\lambda} + c_{NAP} \beta_{NAP,\lambda}}$$

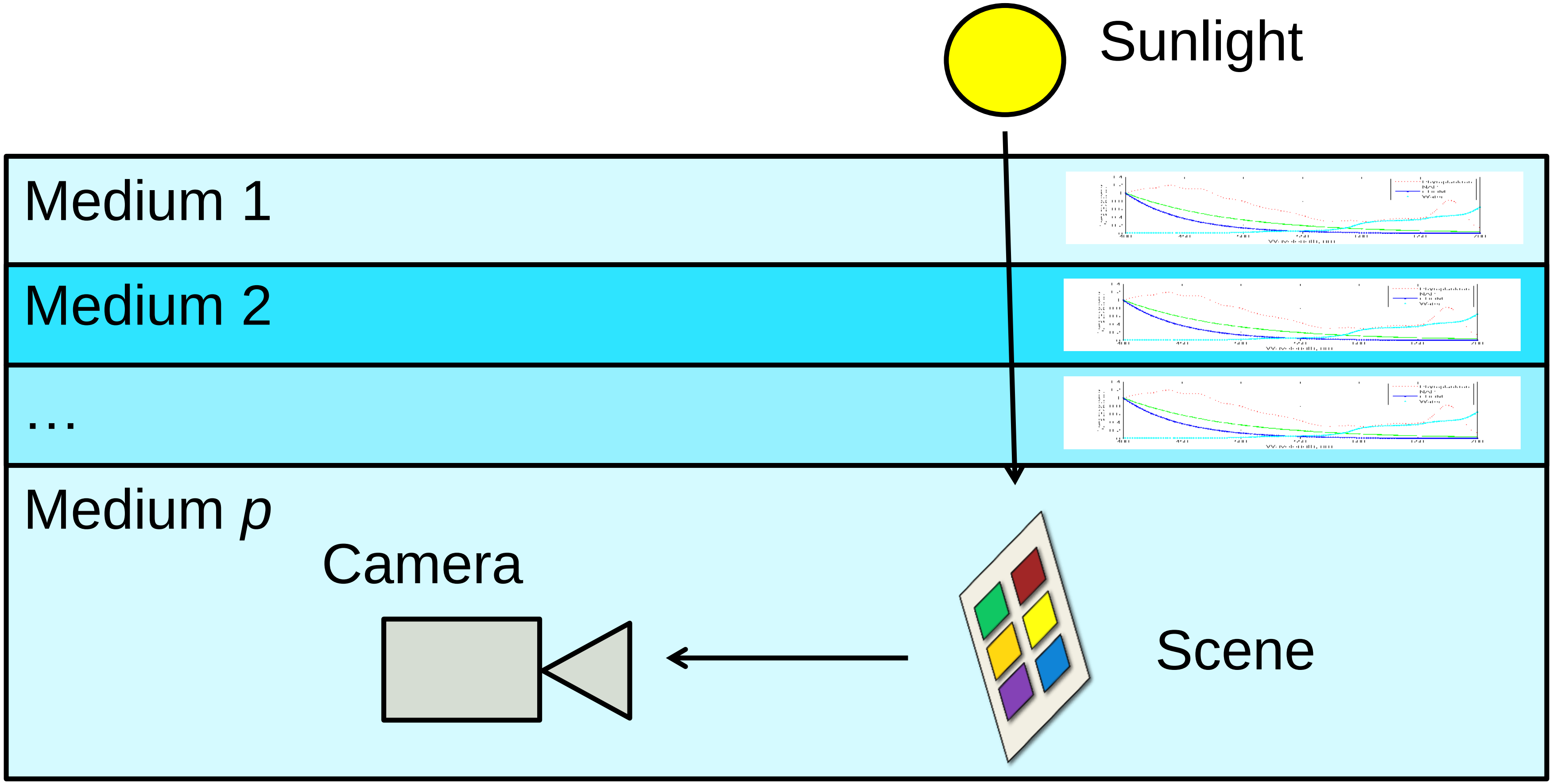
$$m_j = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-D_p a_\lambda}$$

Lossy Medium With Absorption Basis



$$m_j = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-D_p a_\lambda}$$

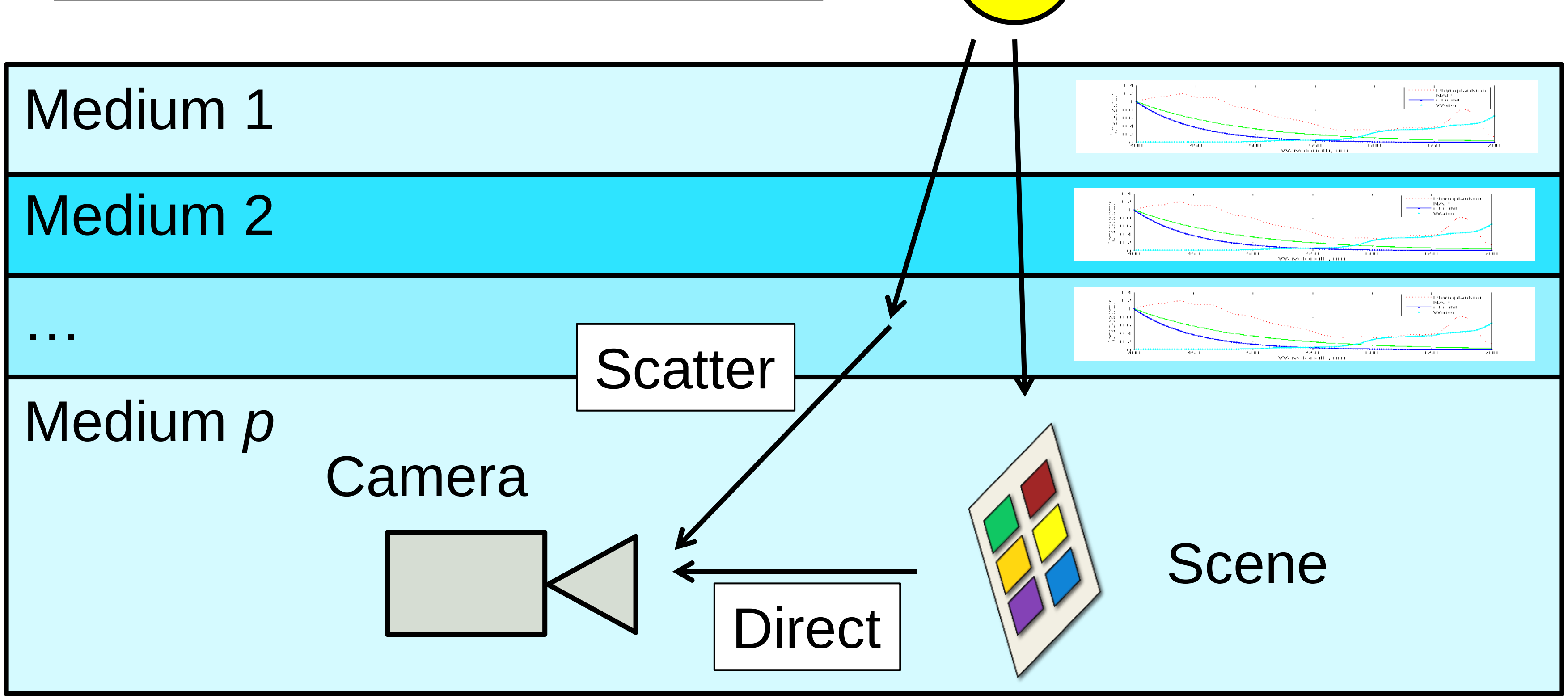
Multilayer Lossy Medium



$$m_j = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-\sum_{l=1}^{p} a_{l,\lambda} \Delta d_l}$$

Multilayer Lossy Medium and Scatter

6 unknowns: $c_{\{NAP,CDOM,\Phi\}}, bs_j$



$$m_j = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-\sum_{l=1}^{p} a_{l,\lambda} \Delta d_l} + bs_j$$

Model Estimation

$$\min_{c_{k,l}, bs_j} \sum_{j,t,q} \left| \hat{m}_{j,t,q} - m_{j,t,q} \right|^{\gamma} + \delta R(c_{k,l})$$

$$B_k c_{k,l} \geq 0 \qquad \forall_{k,l}$$

$$b_j \geq 0 \qquad \forall_j$$

For:

$$m_{j,t,q} = g_j \Delta\lambda \sum_{\lambda=1}^{N} s_{j,\lambda} r_{\lambda,t} I_{0,\lambda} e^{-\sum_{l=1}^{p} \alpha_{l,\lambda} \Delta d_l} + bs_{j,q}$$

$$R(c_{k,l}) = \sum_k \sum_l \frac{1}{(d_l - d_{l-1})^{\tau}} \left| c_{k,l} - c_{k,l-1} \right|$$

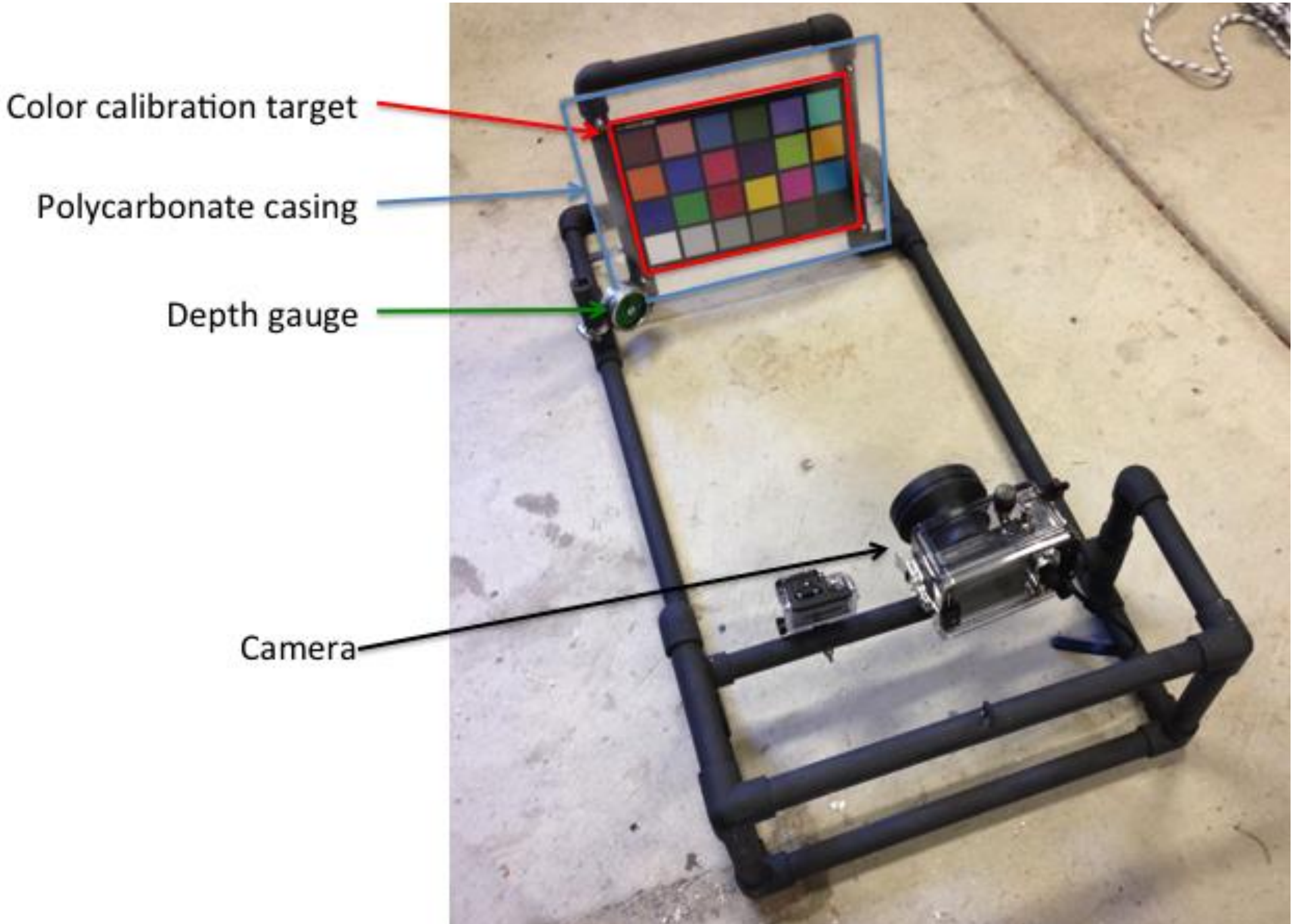
First term quasi-convex, for $\gamma \geq 1$

- m is smooth, convex

Use iterative first-order Taylor expansions for $m \rightarrow$ affine

Solve via *cvx* convex optimization toolbox

Test The Model With An Underwater Color Rig

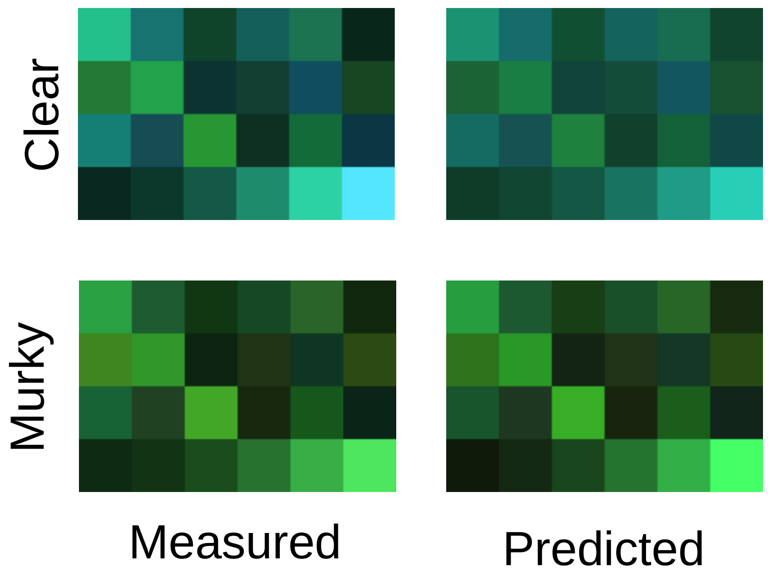


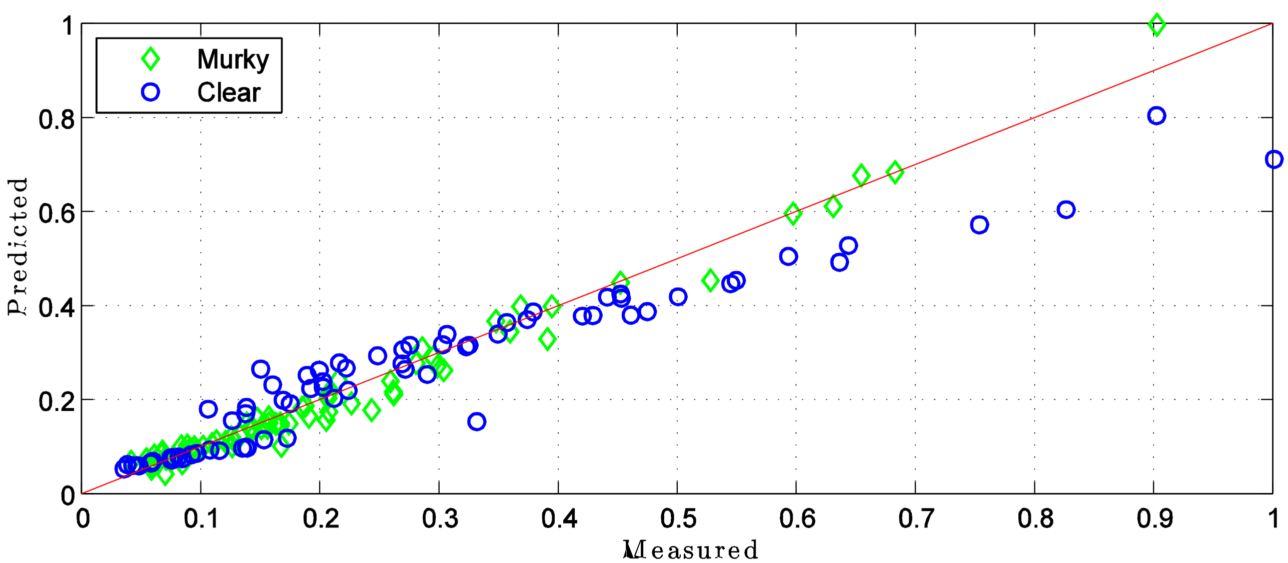
Test The Model With An Underwater Color Rig

Color c

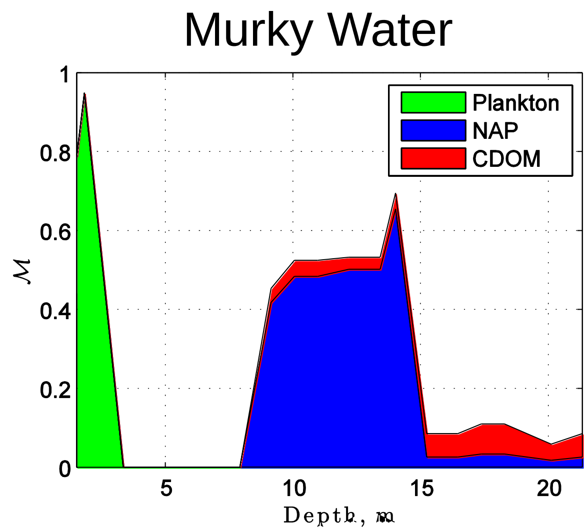
Polyc

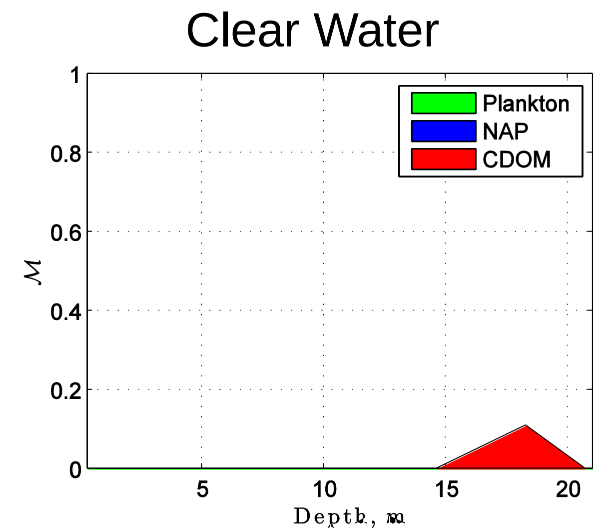
Image Comparison at 10m: Clear and Murky Water

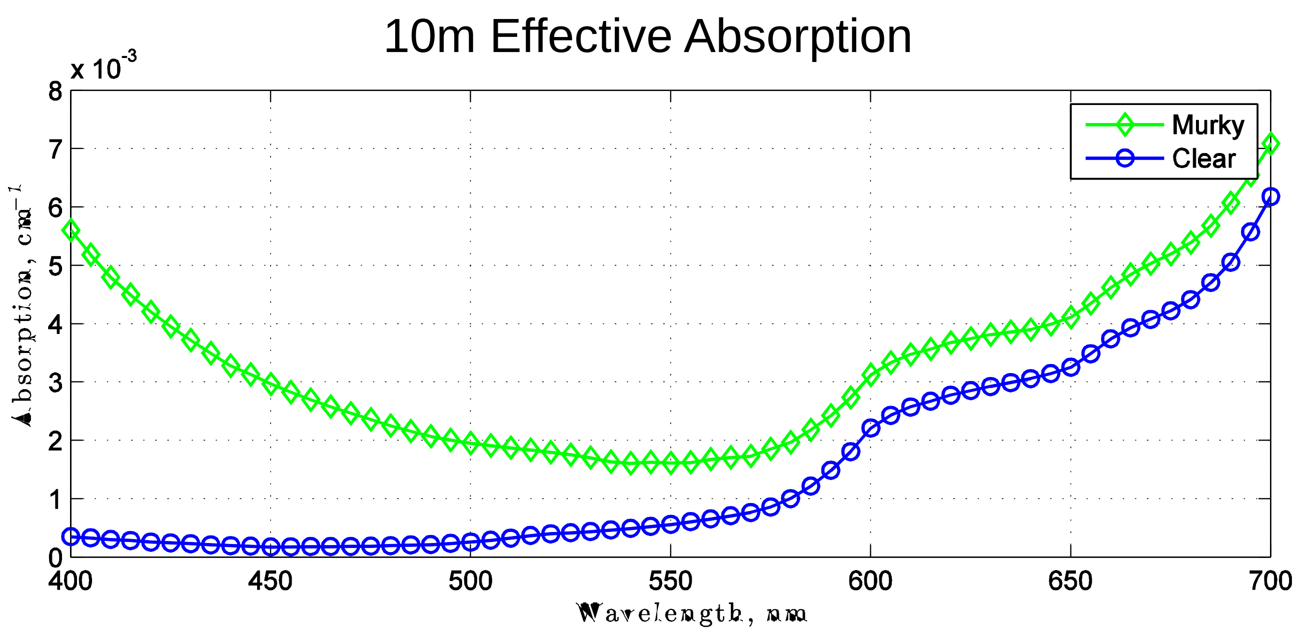




Water Content: Clear and Murky Water







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Color Correction Underwater

Traditional color transform using 3x3 matrix:

$$\begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} R_c \\ G_c \\ B_c \end{bmatrix}$$

Offset color transform using 3x4 matrix:

$$\begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \end{bmatrix} \begin{bmatrix} R_c \\ G_c \\ B_c \\ 1 \end{bmatrix}$$

15% - 50%

$$m_j = g_j \Delta \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-\sum_{l=1}^{p} \alpha_{l,\lambda} \Delta d_l} + bs_j$$

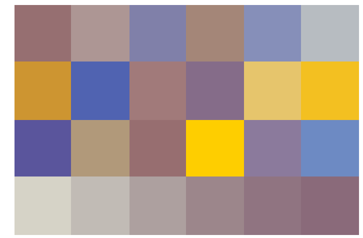
Color Correction Underwater – Murky Dive Example

Traditional color transform using 3x3 matrix:

Reference

5 Meters

20 Meters



Offset color transform using 3x4 matrix:

Reference

5 Meters

20 Meters

$$m_j = g_j \Delta \sum_{\lambda=1}^{N} s_{j,\lambda} r_\lambda I_{0,\lambda} e^{-\sum_{l=1}^{p} \alpha_{l,\lambda} \Delta d_l} + bs_j$$

Summary

Changing depths changes natural illumination
- We can describe this with a physics-based model

Physics model is quasi-convex
- Solve regularized optimization iteratively

Particulate scatter is not handled well by 3x3 color correction schemes
- Build affine color correction transforms

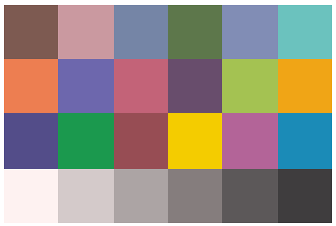
Questions?

Acknowledgements:
Colin Roesler, Annick Bricaud ,Tetsuichi Fujiki, Sumit Chawla

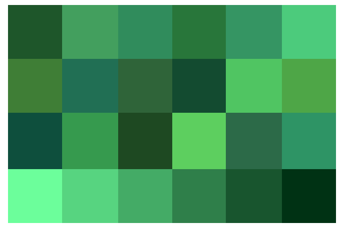
Clear and Murky Water 20m Example

Murky

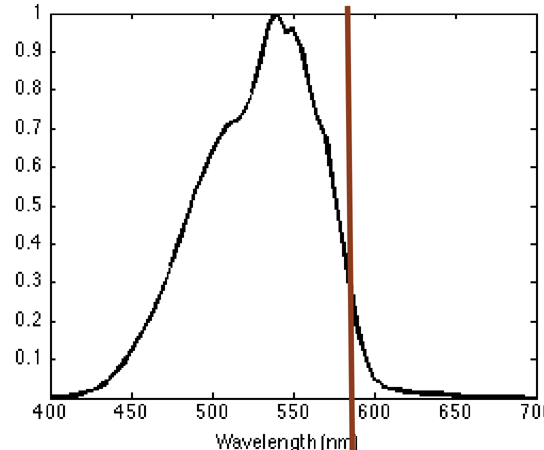
Corrected



Measured



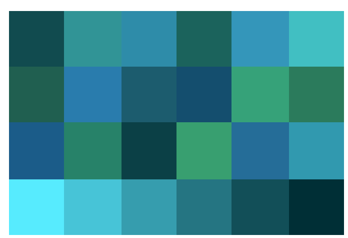
Illuminant



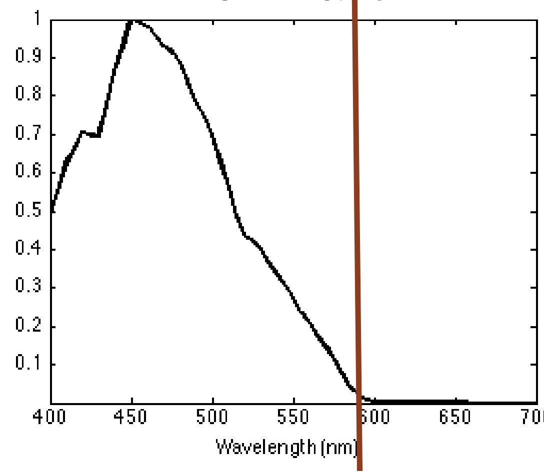
Clear

Corrected

Measured

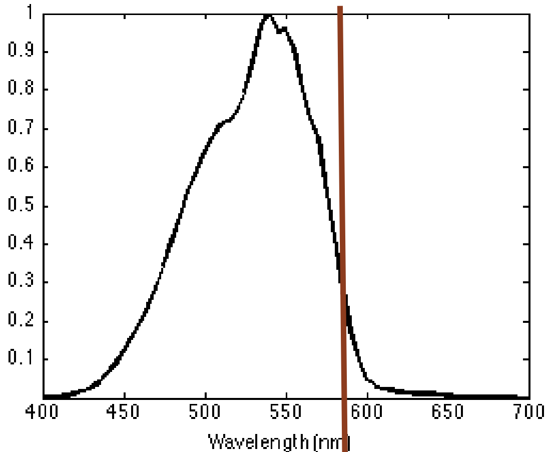


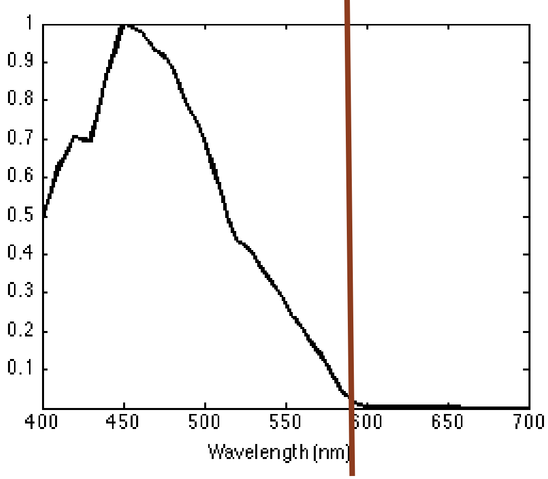
Illuminant



Why does clear water produce poor color?

Water Quality-Independent Color Solutions





1. Bring artificial light
   - Expensive hardware
2. Apply an optical filter
   - Tuned to depth, water content
3. Exposure Bracketing
   - Long exposure ➔ Red
   - Short exposure ➔ Green, Blue
   - Apply 3x4 color transform

Backup – Bi-convex model fitting